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THE COMPARISON ANALYSIS OF SOUND LEVEL EMITTED BY VARIOUS TRAM BOGIES UNDER NORMAL OPERATING CONDITIONS

Pawel Komorski, Tomasz Nowakowski, Grzegorz M. Szymański, Mateusz Motyl and Szymon Finke

Poznan University of Technology, Faculty of Machines and Transport, Department of Rail Vehicles, Poland
email: pawel.r.komorski@doctorate.put.poznan.pl

The noise level increase in large Polish and European cities. It depends directly on urban transport development. Number of inhabitants and passengers complain on annoyance vibroacoustic signals emitted by light rail vehicles during passage rise up. Moreover the noise problem is noticed by cities authorities and public transportation operators. The light rail traffic noise reduction is important especially in case of city life comfort improvement. Therefore the noise requirements for tram producers are increasing in terms of reduce the main sound sources – rolling and drive unit noise. In this case the main sound sources are tram bogies. It is well-founded to do regular tests and comparison analysis of external sound sources in existing constructions of tram bogies under normal conditions. The research results can be used to verify the further projects of tram bogie construction.

In the article is presented the comparison analysis of sound level emitted by different types of tram bogies during pass-by tests. The research consists of several acoustic measurements using microphone matrix located in near field from moving sound sources. Three types of trams were analysed. Passage speed of each tram was about 50 km/h. Then the comparison analysis was conducted in time and frequency domain.

Keywords: noise, light rail vehicles

1. Introduction

Tram noise has a big influence on inhabitants life comfort inside Polish and European cities. The main external sound sources during tram passage are rolling noise and traction noise [5]. It could be concluded that tram bogies are main noise sources and different constructions may have different influence on the noise emission. In [1-2] are shown various tram acoustic signatures which means different sound structures in case of qualitative and quantitative analysis. The tram acoustic signature depends mostly of a tram construction, speed and type of rail track. Moreover to reduce a noise emission in near field of vehicle sound sources can be used elastic wheels [4] or some other sound dumpers. Also different types of bogie covers can mitigate noise emission up to 2.5 dB [3-4]. Other example of noise reducing method is the acoustic absorb materials usage around free spaces on tram bogies (as the new tram from Poznan – the Moderus Gamma tram).

In this article is presented the comparison sound level emitted by various tram bogies under normal operating conditions. The acoustic measurements are carried out on three tram types. The tram acoustic signature analyses are shown in case of time and frequency domain. The acoustic maps are presented in which the main noise sources are shown. Also the constant percentage bandwidth analyses in time domain are calculated to each noise tram. Based on that, the main characteristic frequency bands were selected to show acoustic signature differences between tram construction types.

2. Research objects

Three types of trams were selected to investigation: Solaris Tramino S105p, Moderus Beta MF02 AC and Tatra RT6N1 (Fig. 1). All of them are still operated on Poznan tram infrastructure (track width: 1435 mm, power supply: 600 VDC). Main technical parameters of research objects are shown in table 1.

a) **b)** **c)**

Figure 1: Three tram types: a) Solaris Tramino S105p, b) Moderus Beta MF02 AC, c) Tatra RT6N1.

Table 1: Main technical parameters of three research trams

Manufacturer	Solaris	Modertrans Poznan	ČKD/HCP-FPS
Model	Tramino S105p	Moderus Beta MF 02 AC	Tatra RT6N1
Length	31960 mm	28250 mm	26 280 mm
Width	2400 mm	2350 mm	2440 mm
Tram segments number	5 (included 2 in-termediate vehicle modules)	3	3
Tram joints number	4	2	2
Motor bogies number	2 (the first and the last one)	4	2
Trailer bogies number	1 (the middle one)	0	1
Percentage of low floor	100%	25%	63%
Motor engine number	4 (105 KW each one)	8 (41,5 KW each one)	4 (104 KW each one)
Maximum speed	70 km/h	70 km/h	80 km/h

Main differences between tram bogies are in construction and manufacturer aspects. Chosen technical objects are representation group of light rail vehicles in new construction type which are mostly operated in European and Polish cities (next to old, high floor trams).

3. The methodology of research

3.1 Measurements method

Acoustic measurements were carried out in Poznan Franowo depot area during daily hours. The measurement localization is shown on the Fig. 2. The experimental straight track is marked by red line and the measurement point is marked by green PP point. The pass-by tests were performed where the maximum speed of each tram passage was 50 km/h in PP measurement point. Seven measurement series were performed for each tram. Then the acoustic signals were averaged to each research object.

Fig. 2. Measurement localization on the Poznan Franowo depot: the experimental track is marked by red line; the measurement point PP is marked by green colour [based on Google Maps view]

Measurement devices from Brüel&Kjær Company were used to acoustic signal recording. The measurement chain is shown on the Fig. 3.

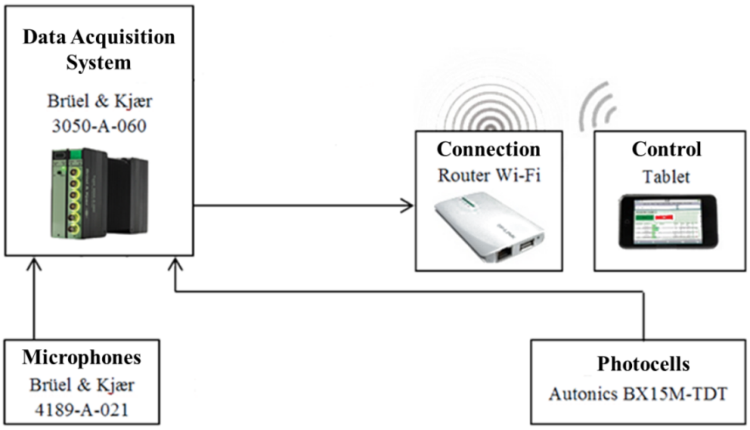

Fig. 3. Measurement chain

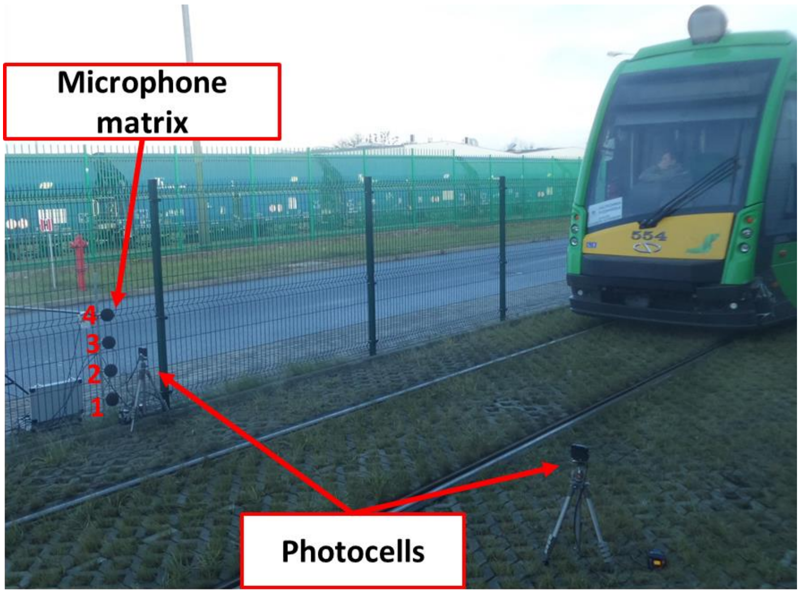

Fig. 4. Measurement view in the PP measurement point

The four microphone matrix was located in near field from sound source, at distance 1 m from outer rail (fig. 4). The distance between each microphone is about 200 mm. On the Fig. 4, the measurement position with all devices is shown. Two photocells were located on both sides of the track. Signal emitted between them were used to point the start and the end of tram passage – the measuring cross section was selected. Furthermore, the time selection of signal measurements was able to determine. Therefore, all acoustic measurements were harmonized in speed domain.

The weather conditions during measurements: temperature was about 10 Celsius degree, lack of rainfall, relative humidity was about 60%, slightly cloudy and speed wind was less than 3 m/s. The main aspect in case of making acoustic measurements is background noise level. For all measurement series, the background noise level wasn't higher than 60 dB which means no influence on research conditions.

3.2 Signal processing methods

The acoustic signals were synchronized in all four measurement points. Based on photocells recording, the signal selection in time domain was performed. Average tram passage time by measurement section was equal to 2 seconds. The tram speed was about 50 km/h (with tolerance 1 km/h). Results of signal processing were A-weighted equivalent sound pressure level L_{Aeq} in time domain, with 1 ms time interval, in accordance to equation (1):

$$L_{Aeq,\Delta tpk} = 10\log\left(\frac{1}{t_p - t_k}\int_{t_p}^{t_k}\frac{p_A^2(t)}{p_0^2}dt\right) \tag{1}$$

Where Δt_{pk} is the tram passage time by the measurement point (the observation time), p_A is the A-weighted sound pressure, p_0 is the reference sound pressure value (p_0= 20 μPa), t_p is the time of measurement start, t_k is the time of the end of measurement.

On the basis of sound level calculation from each microphone the acoustic maps were elaborated. Distribution of temporary acoustic field was shown. In this way, the main noise sources of tram bogies have been located.

Also the CPB (Constant Percentage Bandwidth) analyses in time and frequency domain were calculated. The audible frequency bandwidth has been taken into account and also A-weighted characteristic was applied. In this case, the characteristic frequencies noise analysis was performed.

4. Results

4.1 The comparison in time domain

Acoustic maps with sound field propagation around tram noise sources are shown in Fig. 5-7. The A-weighted sound level color scale in decibels is attached under each map. Various colors are pointing different sound pressure level in audible frequency bandwidth. Each tram picture is turned up in the same way – the vehicle front is situated on the right side. Also this is a passage direction (from left to right side on figures).

First results are for Solaris S105p tram. The highest sound pressure level on the Fig. 5 is located around motor bogies. Furthermore, it can be concluded that microphone No. 1 (located in lowest matrix point) measured the highest sound level around first motor bogie which was equal to 96 dB. While microphone No. 4 in the same measurement section recorded lower sound pressure by 4 dB. Sound pressure levels measured around the second motor bogie are 2 dB less than those around the first one (respectively: 94 dB in microphone No. 1 and 90 dB in microphone No. 4). Trailer bogie (the middle one) emitted the lowest sound pressure levels during pass-by tests only around measurement point's No. 3 and 4 which was only 88 dB. It is related to bigger distance from rolling noise (wheel-rail interaction) and lack of motor and gear units. So in this case rolling noise was equal to 94 dB (measured by microphone No. 1). Lastly, the temporary noise around two tram intermediate modules was reduced by 15 dB than noise around bogies and it was equal to 78-81 dB.

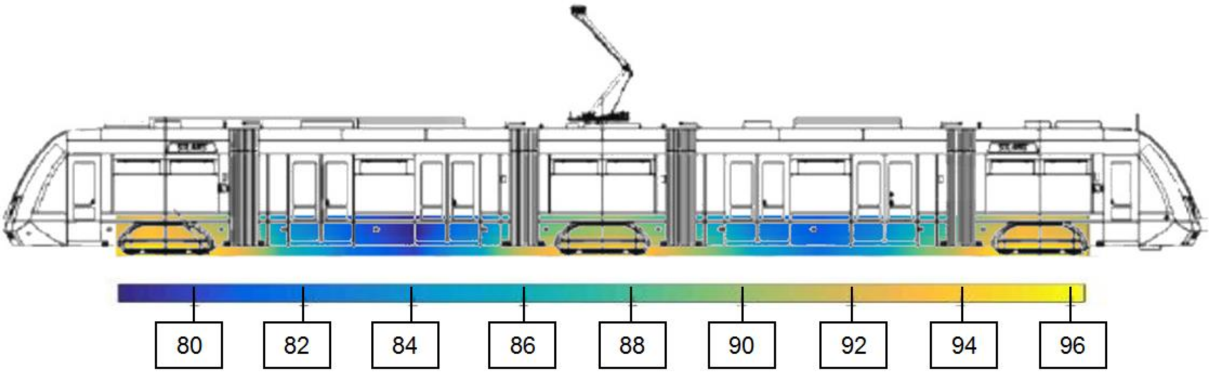

Fig. 5 Acoustic map of sound field propagation around Solaris Tramino during pass-by test

The Tatra RT6N1 is shown on the next acoustic map (Fig. 6). Sound pressure level around the trailer bogie (the middle one) area was equal to 88 dB (measured by microphone No. 1). It is the highest noise level and it is related with rolling noise. Probably in this case wheels were more wear than in other bogies because wheels diameter was lower. In both motor bogies, the highest sound pressure level was about 87 dB in the first measurement point. While in the fourth microphone in the same measurement section it was about 83 dB. The difference in noise emission between Tramino (Fig. 5) and Tatra (Fig. 6) is significant and it is equal nearly to 8 dB in the highest noise area.

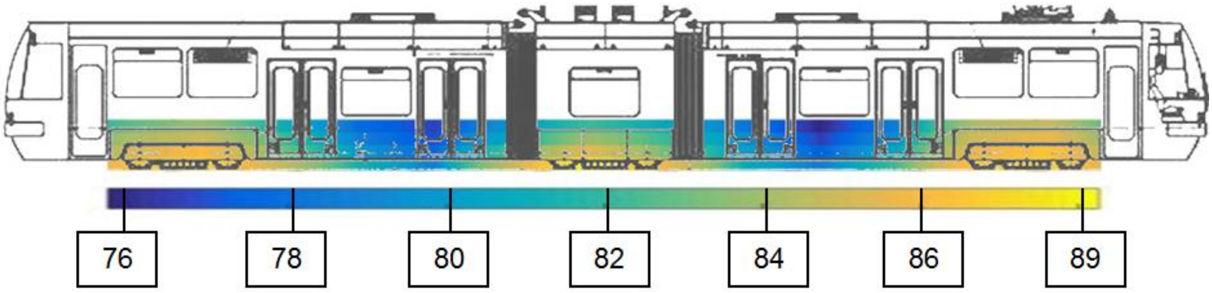

Fig. 6. Acoustic map of sound field propagation around Tatra during pass-by test

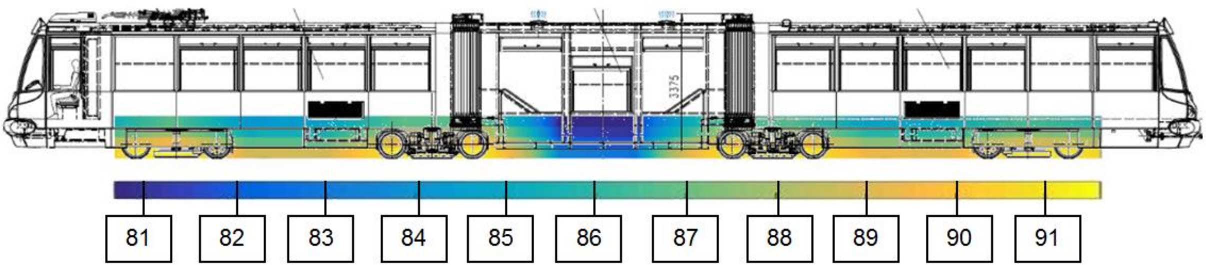

Fig. 7. Acoustic map of sound field propagation around Beta during pass-by test

On the third acoustic map is shown the last research object - Beta MF02 AC (Fig. 7). In this case there are four motor bogies and the highest sound pressure level was equal to 91 dB on each one (measured in the lowest measurement matrix point). In other measurement matrix points the noise is reduced to 86 dB. The main sound sources are rolling and traction noise. However the traction noise (engine and gear noise) is not as high as in Tramino case. The engine units in Beta tram bogies are less power than in Tramino. In measurement section around the middle part of tram (the tram intermediate module) the sound pressure level was lower by nearly 10 dB (the blue color).

4.2 The comparison in frequency and time domain

Time-spectrum maps calculated based on pass-by measurements are shown on Fig. 8-10. Acoustic signals recorded by the first microphone were used to make each map. Rolling and traction noise were the highest one around this area. Also for each map was used the same time, frequency and sound level scales which facilitated the comparison.

The time-spectrum map of Solaris Tramino S105p passage is shown on the Fig. 8. There are three yellow patterns which can be observed, characteristic for pass-by three tram bogies. The lowest situated pattern (in 0,4 s) is noise emission of the first motor bogie. The characteristic frequency bands for yellow color (sound level between 90-100 dB) are from 160 Hz to 1 kHz in general. While main frequency bands of trailer bogie noise emission are located in 400-500 Hz (where noise level was 100 dB). In the case of motor bogies noise emission, the sound level in 800 Hz spectrum band was the highest one and equaled 100 dB.

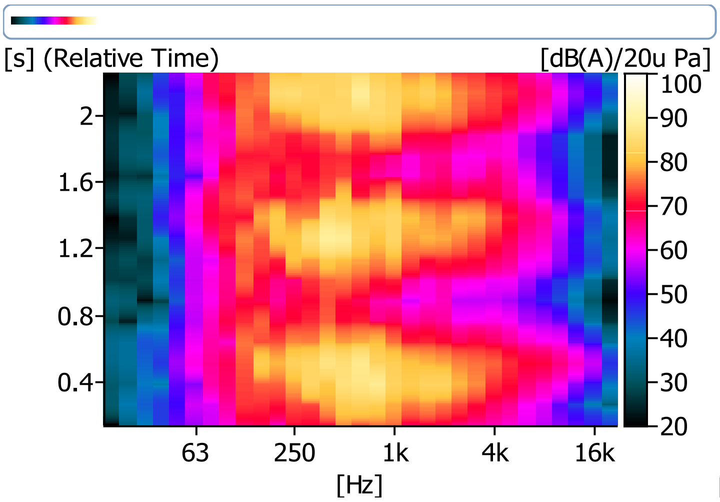

Fig. 8. Time-CPB map of Solaris Tramino

The second time-frequency map is shown on the Fig. 9, where Tatra RT6N1 analysis is performed. There are also three yellow patterns. However these are not as visible as on the Tramino analysis. The trailer bogie emitted the highest noise level which is located in 800 Hz and it equaled above 90 dB (the most yellow pattern in the middle of map). Characteristic frequency bands are 500-1000 Hz where noise level was between 80-90 dB. Furthermore, the noise level in 2.5 kHz spectrum band is also increased to nearly 85 dB. In case first motor bogie, the highest sound level is located in 630 Hz frequency band. When Tramino and Tatra sound fields are compared in general aspect, the more red patterns (sound levels between 70-75 dB) are visible in Tatra analysis.

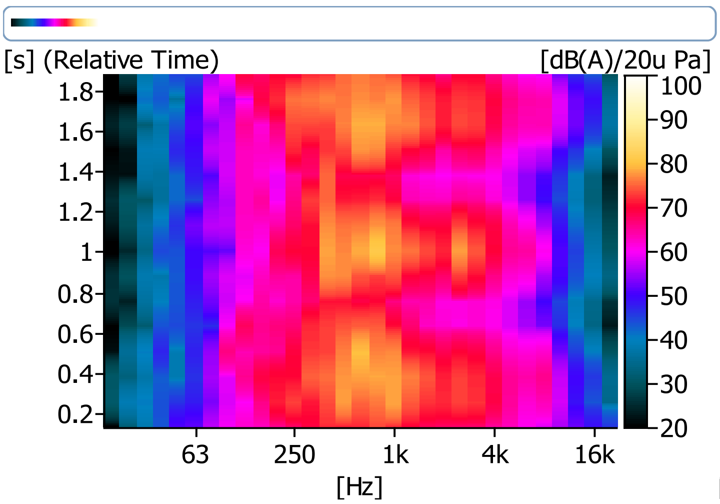

Fig. 9. Time-CPB map of Tatra

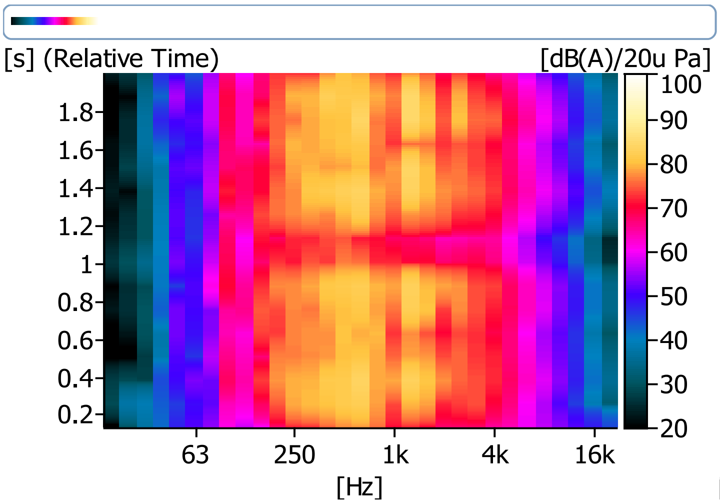

Fig. 10. Time-CPB map of Beta

On the last time-spectrum map (Fig. 10), the Beta MF02 AC analysis is shown. The red gap on the middle of map can be observed which means pass-by of silent part of tram (the tram floating segments). While between 1-2 kHz frequency bands can be seen division on four yellow patterns which is described by four motor bogies in whole time domain. Characteristic frequency bands are 250-800 Hz, 1250 and 1600 Hz where sound level was between 90-100 dB. Predominant frequencies are 400-630 Hz and 1250 Hz. In global sound field comparison, Beta is located between Tramino and Tatra in case of quantitative noise analysis in time and frequency domain.

5. Conclusions

The comparison research of near field noise emission and main sound sources localization were carried out. Rolling noise (wheel-rail interaction) and traction noise (motor and gear noise, construction clearances or defects) emission were analyzed in time and frequency domains during pass-by test. Based on investigation, it can be concluded that:

1. The highest A-weighted sound level was emitted by Tramino S105p which was equal to 96 dB. The main sound sources were rolling and traction noise emitted by tram bogies and recorded by microphone No. 1. The lowest sound level (by 15 dB) was in tram intermediate segments area.
2. The second tram with sound level above 91 dB (measured by microphone No. 1) was Beta MF02 AC. This tram is equipped with four motor bogies. The lowest sound level was 80 dB in the middle area of the tram.
3. In comparison, the Tatra RT6N1 emitted the lowest sound level in measurement section of trailer bogie which was equal nearly to 88 dB. While sound level emitted by motor bogies was less by 1-2 dB. The lowest sound level was about 76-77 dB and it occurred in area where are no tram bogies.
4. Main characteristic noise frequency bands for all three research objects are 400, 500, 630, 800 and 1000 Hz. In those spectrum bands, the sound levels were the highest (nearly 100 dB) during tram bogies pass-by.

Public transport operators and rail vehicle manufacturers have to be aware of acoustic problem. There are plenty of methods to reduce noise during operating conditions in tram life cycle. However in case of cost and comfort analyses, it is worth to think about noise mitigation aspect in early design stage of tram construction.

Acknowledgements

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